Final Synopsis

for the Ph.D. Thesis entitled

STUDIES ON RESIDENT AND MIGRATORY BIRD SPECIES WITH REFERENCE TO HABITAT, FEEDING PATTERNS AND VOCALIZATIONS AT LAKE TANA, ETHIOPIA

By

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1.0 Introduction

Birds are diverse with over 10,000 extant species spread worldwide and fill a variety of ecological functions (Tietze, 2018; Brusatte et al., 2015). However, avian distribution and diversity across habitats have been affected, due to various threats to birds and their habitats (Destro et al., 2018; Ormond et al., 2013). Changes in species richness, abundance, distribution, and feeding diets need to be regularly assessed to ascertain effects of habitat change on bird populations (Tietze, 2018; Romano et al., 2005). As a result, the purpose of this work was to record diversity and abundance of avifauna on lake Tana in relation to habitat, feeding patterns and vocalizations.

1.1 Objectives

- To survey the diversity and abundance of birds (both resident and migrant)
- To record the seasonal distribution of birds (both resident and migrant)
- To record avifauna-flora relationships in terms of habitat and food
- To analyse bird vocalizations/song
- To assess anthropogenic impact at lake Tana using LULC changes

2.0 Literature review

2.1 Avian diversity and abundance

Two thousand genera belonging to 30 orders of birds are distributed worldwide (Sobhakumari et al., 2018; Mayr, 2016; Brusatte et al., 2015). Avian abundance and distribution depends on vegetation, food resources and water bodies (Del Hoyo and Collart, 2019; Maletz, 2017; Ash and Atkins, 2009). As a result of changing habitats, distribution varies constantly with some species expanding; others declining; and still others fluctuating by expanding and then declining their range (Sekercioglu et al., 2008; Jetz et al., 2007). Some bird species have faced extinction risks (Whelan et al., 2015). Tropics, despite having highest abundance and diversity of avifauna (Brandes, 2008) are on the cutting edge of bird extinction and endangerment (Sodhi et al., 2011). Most threatened birds have declining populations (Jetz et al., 2007) with common bird species also facing a downward trend in population and habitats (Ash and Atkins, 2009). Sites are also not visited regularly by ornithologists, resulting in various knowledge gaps (Rannestad, 2016).

2.2 Bird habitats

Bird habitats (Bamford and Calver, 2014) are under threat (Sutherland et al., 2004) due to agricultural expansion, wetland deforestation, land-use change, pollution, and settlement (Goshu and Aynalem, 2017) which affect bird populations. Birds live in habitats that change on a regular and irregular basis over time and space (Hirzel and Le Lay, 2008). Seasonal conditions and reduced food supply contribute to seasonal changes in bird species' richness and abundance (Newton, 2007). Habitat-related factors have contributed to rapid decline in species richness (Lepczyk et al., 2008). Regular monitoring of avian abundance, habitat preference, and the relationship between avian species and habitat provides critical information for determining factors that cause fluctuations in bird population (Norvell et al., 2003).

2.3 Feeding guilds

Habitat use patterns of birds are influenced by seasonal variations in food abundance (Gregory et al., 2004) and thus influence feeding patterns. Seasonal variations in food abundance influence bird migration (Maeda, 2001). *Pterocles namaqua* (Namaqua Sandgrouse) exhibits seasonal variation in habitat use, such as regional movements in response to seasonal food availability (Lloyd et al., 2001). When food is scarce, some birds expand their foraging niches, increase their habitat use (Girma et al., 2017; Lopez de Casenave et al., 2008), and change their diet (Marone et al., 2017). Food availability and exploitation patterns in a specific habitat determine bird distribution and community structure (Pang et al., 2017; Magurran and Mcgill, 2011). Feeding guilds have a significant impact on avian diversity, abundance, and distribution (Palmer et al., 2003). Seasonal effects (Kumar and Sahu, 2020; Nsor et al., 2018) besides habitat degradation (Asefa et al., 2017) are two factors that influence foraging behavior. Food availability and the distance between the feeding and roosting sites also influence bird distribution (Maneas et al., 2020; Vyas and Veerwal, 2014).

2.4 Bird vocalizations

Birds use calls, songs, and mechanical sounds to communicate, which can be used as effective tools to survey birds (Brandes, 2008) due to unique and distinct acoustic characteristics (Debnath et al., 2016; Szewczak and Morrison, 2010). As a result, automated methods for bird surveillance investigate avian diversity in a given ecosystem using vocalization. Song and calls are best

developed in Passeriformes (Potamitis et al., 2014). Five thousand bird species belonging to Oscines, Apodiformes and Psittaciformes are known to learn their songs or calls. Acoustic recordings of bird calls/song constitute one of the methods of biodiversity assessment (Sueur et al., 2008). This survey method has been shown to increase the accuracy of avian surveys over larger temporal and spatial scales (Szewczak and Morrison, 2010) as bird songs and calls are distinct and identifiable at the individual level. Although bird vocalizations are important for population dynamics, monitoring, communication, and determining the occurrence of bird species (Farina and Gage, 2017), no study has ever been conducted and published on vocalizations of Ethiopian birds.

2.5 Threats to birds

Bird populations are declining, indicating a serious threat to biodiversity (Wang et al., 2020) due to factors (Destro et al., 2018; Ormond et al., 2013) such as habitat destruction, fragmentation, and loss, as well as changes in land use (Wang et al. 2020; Nergiz and Durmuş, 2017). Decreased bird diversity and abundance are likely to have significant ecological implications (Lepczyk et al., 2008). According to Waltert et al. (2004), unsustainable land use has led to the decline of common species in tropical regions. Deforestation for cultivation reduced species richness by 60%, with loss of more frugivores and insectivores than omnivores (Aratrakorn et al., 2006), while reduction in forest cover harmed the diversity of forest-dependent frugivores and insectivores (Morante-Filho et al., 2015). According to Gonzalez-Gajardo et al. (2009), bird species richness are influenced by vegetation, area of wetland, water level fluctuations, and length of shoreline.

2.7 Ethiopia - **Avifauna**

Ethiopia has diverse avifauna (920 species), accounting for 39% of Africa's bird species (Ash and Atkins, 2009). 665 of these species are residents, while 246 have been recorded as migrants (Duck et al., 2010; Sinclair, 2009). Although Ethiopia has a rich and diverse avifauna, rapid habitat destruction, land use changes, cultivation, deforestation, pollution and shoreline development activities, have led to the decline and alteration of habitats, resulting in extinction (Asefa et al., 2017; Goshu and Aynalem, 2017). To combat this, Ethiopia has established over 73 Important Bird Areas (IBAs), with wetlands accounting for 41% of these sites (Tulu and Desta, 2015; Abebe and Geheb, 2003). Lake Tana is one of the IBAs (Israel and Timar, 2018; Abebe

and Geheb, 2003) and a UNESCO world biosphere reserve (Bires and Raj, 2019) in the Amhara province of northern Ethiopia.

The main threats to lake Tana sub-basin include forest destruction, overgrazing, sedimentation, agricultural expansion, invasive weeds, drainage of wetlands, and pollution (Abebe and Minale, 2017). Vegetation removal (e.g., Papyrus) is common (Goshu and Aynalem, 2017). Trees such as *Ficus* spp. are commonly used by birds for resting, feeding and nesting. Earlier studies carried out on birds by Aynalem (2017), Aynalem and Bekele (2008 and 2009), and Tassie and Bekele (2008) in lake Tana at different sampling sites limited geographically to the southern and northern parts of the lake have focused on avian composition, abundance, distribution and habitats (Table 2.1). Studies on land use land cover (LULC) changes in parts of lake Tana also exist (Sewnet, 2015; Gashaw and Fentahun, 2014). However, studies on bird population, seasonal distribution and feeding patterns are lacking in the western and eastern parts of the lake. Furthermore, no studies exist on recording and analysis of vocalizations of birds at lake Tana.

Table 2.1 Summary of studies carried out at lake Tana with geographical coordinates

Region of lake Tana (Latitude and longitude)	**Major findings**	**References**
11º37′N, 37º25′E	129 bird species including 03 endemics, 02 globally threatened, and 21 migrants were identified.	Aynalem and Bekele (2008)
11°37′-11°43′N 37°19′-37°25′E	101 bird species identified, including 91 residents and 10 Palaearctic migrants, with higher species richness in the dry season.	Aynalem and Bekele (2009)
$12^0$15′30″-$12^0$18′N $37^0$20′30″-$37^0$29′E	193 bird species identified, and their habitat use varied significantly, with a strong preference for farmland and modified habitats.	Tassie and Bekele (2008)
10°55′-12°45′N 36°40′-38°20′E	Lake basin harbors 437 bird species including 112 Palaearctic and 07 Afrotropical migrants.	Aynalem (2017)
$11^0$30′-$11^0$50′N $37^0$20′-$37^0$20′E	LULC impacted crane by reducing 27.6% of the wetland. Chimba wetland was the hardest hit.	Zelelew et al. (2021)
11°48′-12°40′ N 37°7′-37°41′E	Classified wetlands into riverine, lacustrine, palustrine, or artificial. The main threats were mentioned.	Aynalem et al. (2017)
11°36′-12°14′N 37°18′-37º25′E	Wetlands converted into agriculture and grazing land and main threat to crane species at Yiganda.	(Aynalem et al. (2013)
11°40′-12°14′N 37°19′-37°41′E	Most populations of Black Crowned Crane (94%) and Eurasian Crane (36%) found in lake Tana area, but	Aynalem et al. (2018)

	threatened by agricultural practices.	
11^{0}58'00"N, 37^{0}41'E	Wetlands are disappearing rapidly, due to unsustainable farming practices.	Atnafu et al. (2011)
10°55′-12°45′N 36°40′-38°20′E	Built-up and cultivated lands increased from 1986 to 2013, while natural forest and grassland decreased.	Abebe and Minale (2017)
10°58′-12°47′N 36°45′-38°14′E	Wrong reports have resulted in less government attention and a lack of appropriate management.	Bires and Raj (2019)
11°54′29.11″N, 37°20′40″E	Urban and agricultural areas are severely degraded, but wetlands are held in high regard.	Wondie (2018)
10°57′-12°47′N 36°38′-38°14′E	Land, soil, and water degradation observed. The major concerns are food security and environmental sustainability.	Goshu and Aynalem (2017)
10°57′-12°47′N 36°38′-38°14′E	Anthropogenic pressure is destroying and converting wetlands.	Mohammed and Mengist (2018)

2.8 Residents vs. migrants

The distribution of avian species is determined by the availability of suitable habitats and food resources (Tellería and Pérez-Tris, 2003). This relationship is especially exciting in migratory birds. Birds migrate to meet biological needs, such as finding suitable feeding and breeding grounds (Abebe and Geheb, 2003). Migratory behavior allows birds to take advantage of seasonal resources. However, seasonal distribution of avifauna has received less attention in Ethiopia (Girma et al., 2017).

2.9 **Bird Survey**

Survey methods for avian composition and abundance are diverse (Sutherland et al., 2004; Steinkamp et al., 2003). In many cases, point counts (PCs) including 10-minute species counts (TMCs) and line transect are the preferred survey methods (Gregory et al., 2004). Both methods are extremely adaptable, used in aquatic and terrestrial environments (Bibby et al., 2000) and to investigate bird-habitat relationships and to calculate relative and absolute measures of bird abundance (Table 2.2).

Table 2.2 Comparison between survey methods as per Sutherland et al. (2004), Bibby et al., (2000).

Point count	Line transect
Good for access restricted habitats	Used for large, open, and accessible habitats
Used for cryptic, skulking, and shy species	Used for mobile, and conspicuous species
Best for high density and diverse species	Best for low density and fewer species
Give time to identify shy birds	Cover more area and record more birds
Better suited to bird–habitat research	Can be used to study bird–habitat

The point count method is preferred for multi-species surveys (Buckland et al., 2008), surveys of wetland birds, terraced agricultural fields, and in difficult terrain (Whitworth et al., 2007). The practical benefit of using point count is that it allows to investigate habitat associations (Buckland et al., 2008). Considering this, point count method was used for this study.

3.0 Diversity and abundance of birds

3.1. Introduction

Lake Tana is an IBA (Israel and Timar, 2018) and a UNESCO world biosphere reserve (Bires and Raj, 2019; Goshu and Aynalem, 2017) in northern Ethiopia's Amhara province. It is home to 437 bird species from 78 families, dominated by Accipitridae with 39 species (Aynalem, 2017). It also harbours 06 globally threatened species, and 35 highland biome species. Furthermore, the lake sub-basin is home to 15 endemic bird species, some of which are shared with Eritrea (Heide, 2012). Migratory birds use the Dembia and Fogera plain, part of lake Tana, as roosting and feeding sites. For instance, Palearctic and Afrotropical migrants spend the winter in the lake Tana's Shesher-wallala wetlands (Aynalem, 2017). However, deforestation, agricultural expansion, overgrazing, overfishing, pollution etc., pose threats to the lake and its associated avifauna. Therefore, more research on avifauna diversity, abundance, distribution in different habitats at lake Tana is required.

3.2 Methods

3.2.1 Site Selection

The study was carried out at Lake Tana Biosphere Reserve (Fig. 3.1). The biosphere reserve has a total area of 6972 km^2, of which 3042 km^2 is aquatic and 3930 km^2 is terrestrial (Kalmbach, 2017). It contains a large number of both core and buffer zones. The core zones include riparian

and aquatic habitats with less human disturbance, with vegetation such as papyrus stands, and remnant forest on islands (Heide, 2012). Buffer zones are found around core zones, and also separately in areas that are considered important for conservation, restoration, and corridors, but have a high level of human activity (Kalmbach, 2017).

Based on previous studies (Table 2.1), the study sites were chosen from core and buffer zones (Kalmbach, 2017; Heide, 2012). These include an island as the core zone, as well as grasslands, cultivar, and urban areas as buffer zones due to their proximity, within 500 meters, to the Lake's shore as per Heide (2012). A total area of 188.496 ha was covered in the study at all four sampling sites. The same area of 47.124 ha was used in each of the sampling sites (Fig. 3.1). The following are the specifics of the sampling sites that were chosen:

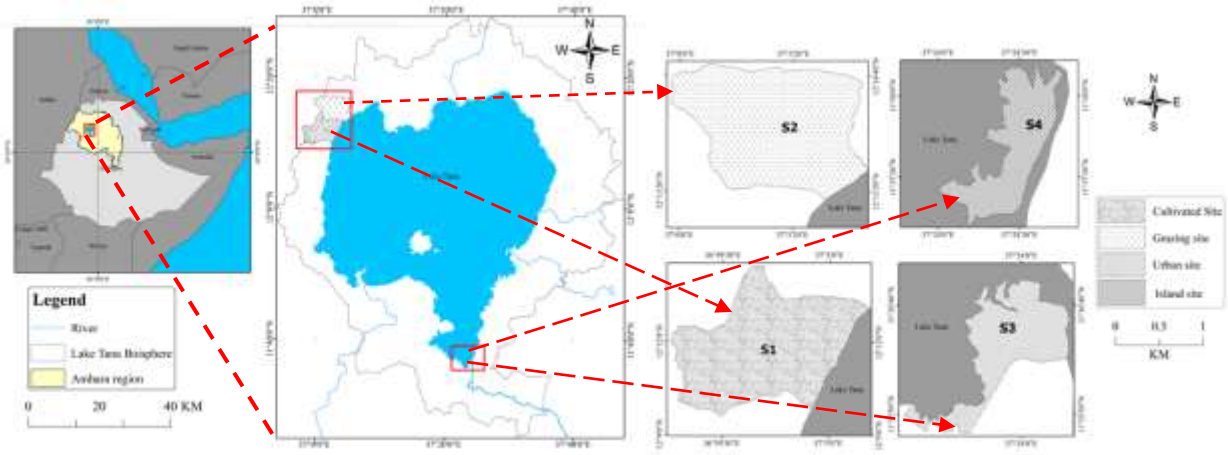

Figure 3.1 Geographical location of the study area. Left panel indicates the location of Ethiopia in Africa, and the middle is the location of lake Tana. The right panel shows sampling sites.

Debre Maryam Island – it is located at the southern parts of the lake (11.621°-11.628°N, 37.402°-37.409°E), near to Blue Nile outlet and Bahir Dar city. Patches of native trees cover the area. Local farmers are disturbing the site by collecting *Cyperus papyrus* and cultivating Avocado (*Persea americana*), Khat (*Catha edulis*), and Mango (*Mangifera species*).

Grazing – located on the northwestern shore of Lake Tana (12.104°-12.121°N, 37.025°-37.033°E). The site serves as a major grazing area for large cattle herds. Heavy livestock grazing and vegetation clearance have resulted in overuse and unregulated management practices. The invasion of weeds is aided by the clearance of wetland vegetation.

Cultivar – located on the northwestern shore of Lake Tana (12.093°-12.103°N, 37.021°-37.024°E). Cultivation is widely practiced by local communities in this area, all the way to the lake's periphery. Farmers intrude on the wetland since there is no delineated boundary between private farm fields and the lake region. As a result, farming occupies the majority of the open ground.

Urban – located in southern part of the Lake Tana in Bahir Dar (11°36′N 37°23′E), capital city of the Amhara region. The city is one of the country's fastest growing and largest cities. As the city has grown rapidly, waste release into Lake Tana has become a common and observable issue.

Table 3.1 Description of the study sites at lake Tana.

Zone	Site	Elevation	Latitude/Longitude	Slope	Description
Core	Island	1790m	11.621°-11.628°N 37.402°-37.409°E	0.9%, -1%	Undisturbed area
Buffer	Grazing	1786.6m	12.104°-12.121°N 37.025°-37.033°E	1.1%, -1.2%	Intensive grazing
Buffer	Cultivar	1788.5m	12.093°-12.103°N 37.021°-37.024°E	0.6%, -0.8%	Intensive agriculture
Buffer	Urban	1820m	11°36′N 37°23′E	2.6%, -2.4%	Urbanization

3.2.2 Study design

A pilot study was conducted in May 2019 to gather necessary information about the sites. The field research design was created using the Lake Tana biosphere reserve map, Google Earth, and a preliminary field survey. Based on habitat disturbance in the core and buffer zones, four sites were chosen. Each site was 47.124 ha and was located within 100m of the lake's perimeter.

2020 & 2021 (Monthly and seasonally)

Diversity & abundance	Point count
Seasonal distribution	Point count
Feeding habits	1. Plants
	2. Droppings
Vocalization analysis	Call recordings
LULC change detection	ArcGIS and RS
	LULC maps analysis of period 1987-2017

3.2.3 Bird survey

Point count method was conducted to assess the diversity and abundance of birds as per Bibby et al. (2000), Gregory et al. (2004), Jones (2008) and Sutherland et al. (2004). This method was chosen because it provides better results for high density and diverse species, an index of individual and species abundance, is suitable for inaccessible swamped habitats, allows for more time to identify shy birds, and is better suited to bird-habitat study (Sutherland et al., 2004; Bibby et al., 2000). The point stations were chosen systematically along the periphery of the lake at 200m intervals, with a random starting point. 60 census points with a radius of 100m were strategically placed in the study area.

Counting was conducted from 06:00 to 9:00, and 17:00 to 18:30 (Bibby et al., 2000). Birds were counted in all four selected sampling sites on a monthly basis from June 2019 to May 2021. Each site was counted multiple times. The survey began around the lake's perimeter, where the majority of the surface area and the edges were observable, and went on to identify and count all birds detected within 100m radius. Species composition, species richness and abundance were recorded by stopping briefly for 2-10 minutes (Gregory et al., 2004). Three people were involved in the bird counting per site. Photographs of birds were taken using a Canon camera (model: EOS 1500D) for confirmation. Species-level identification for lake Tana was based on field guides (Aynalem, 2013; Ash and Atkins, 2009; Redman et al., 2009; Sinclair, 2009). Determination of local status and IUCN Red List categories were done based on keys (Lepage, 2022; Aynalem, 2013; Ash and Atkins, 2009) and the IUCN website (www.iucnredlist.org).

3.2.4 Data analysis

Shannon-Wiener Diversity index was calculated as: $$H' = -\sum_{i=0}^{s}(\mathbf{Pi}\,\mathbf{ln}\,\mathbf{Pi})$$

where: H' = Shannon-Wiener index; Pi = Proportion of the i^{th} species; ln = Natural logarithm

Shannon-Wiener evenness index (E) which measures the pattern of distribution of the bird species present in the study area was used to evaluate species evenness. It was calculated using the following formula: $$\mathbf{E = H'/ H_{max}}$$

where: E = Shannon-Wiener evenness index; H' = Shannon-Wiener diversity index; H_{max} = ln(S) = natural logarithm of the total number of species (S)

Simpson's index of dominance (D) was used to assess the relative abundance of bird species by using the formula: $D = 1 - \Sigma Pi^2$

Where: D = Simpson's index of dominance; Pi = Proportion of individual species

Jaccard's index was calculated as follows: $$J = \frac{s_c}{s_a + s_b + s_c}$$

Where S_a and S_b are unique numbers of species to samples a and b, respectively, and S_c = the number of species common to the two samples.

The **Encounter Rate** method was used to describe a species list using relative abundance index based on the number of encounters with individuals per time block. It was calculated using formula:

Encounter rate = Total individual bird observed X 10

Period of observation in hours

Crude ordinal scales of abundance used are given in Table 3.2.

Table 3.2 Encounter rates used to give a crude ordinal scale of abundance (Bibby et al., 2000).

Abundance category (No. of individuals/10 field hours)	Abundance score	Ordinal scale
<0.1	1	Rare
0.1 - 2.0	2	Uncommon
2.1 - 10.0	3	Frequent
10.1 - 40.0	4	Common
> 40.0	5	Abundant

Relative Diversity (RDi):

The relative diversity of families was calculated as per Torre-Cuadros et al. (2007), the ratio of total number of species within a family to total number of species in percentage. It is calculated as follows:

RDi = number of bird species in a family x 100

Total number of species

ANOVA was used to determine the significance of differences in bird diversity at various selected sampling sites.

3.3 Results

A total of 209 bird species from 60 families and 21 orders were identified (Table 3.3). This included 94.7% of the least concerned (LC) species, 1.4% of the critically endangered (CR) species, 1% of the endangered (EN) species, 1.9% of the vulnerable (VU) species, and 1% of the near-threatened (NT) species. Passeriformes had the most species (35.4%), followed by Charadriiformes (13.9%), and Pelecaniformes (9.09%). Representative birds are shown in figure 3.2.

Figure 3.2 A) Vulnerable (VU), B) Near Threatened (NT) and Intra-tropical migrant, C and D) Endemic, E) Palaearctic Migrant (PM), and F) Abundant species

Table 3.3 Checklist of birds identified in the island, grazing, cultivar, and urban sites of lake Tana biosphere reserve. The following superscript letters represent different sampling sites where the species has been observed: [a] – Island; [b] – Grazing; [c] – Cultivar; and [d] – Urban.

Order	Family	English name	Species name	Status	Red List
Island site:					
Pelecaniformes	Ardeidae	Black-headed Heron	*Ardea melanocephala*	R	LC
		Green-backed Heron	*Butorides striata*	R	LC
Anseriformes	Anatidae	White-backed Duck	*Thalassornis leuconotus*	R	LC
		African Black Duck	*Anas sparsa*	R	LC
		Blue-winged Goose	*Cyanochen cyanoptera*	R	VU
Charadriiformes	Charadriidae	Wattled Lapwing	*Vanellus senegallus*	R	LC
	Laridae	Gull-billed Tern	*Gelochelidon nilotica*	PM	LC
Passeriformes	Nectariniidae	Nile Valley Sunbird	*Hedydipna metallica*	R	LC
	Oriolidae	Black-headed Oriole	*Oriolus monacha*	R	LC
	Ploceidae	Baglafecht Weaver	*Ploceus baglafecht*	R	LC
	Laniidae	Red-backed Shrike	*Lanius collurio*	PM	LC
	Muscicapidae	Common Redstart	*Phoenicurus phoenicurus*	PM	LC
	Acrocephalidae	Olivaceous Warbler	*Iduna pallida*	PM	LC
Columbiformes	Columbidae	Black-billed Wood Dove	*Turtur abyssinicus*	R	LC
Accipitriformes	Accipitridae	White-headed Vulture	*Trigonoceps occipitalis*	R	CR
Gruiformes	Rallidae	Baillon's Crake	*Zapornia pusilla*	R	LC
Piciformes	Lybiidae	Banded Barbet	*Lybius undatus*	R	LC
Strigiformes	Strigidae	African Marsh Owl	*Asio capensis*	R	LC
Grazing site:					
Pelecaniformes	Pelecanidae	Pink-backed Pelican	*Pelecanus rufescens*	R	LC
	Ardeidae	Black Heron	*Egretta ardesiaca*	ITM	LC
		Goliath Heron	*Ardea goliath*	R	LC
Anseriformes	Anatidae	Ferruginous Duck	*Aythya nyroca*	PM	NT

Charadriiformes	Jacanidae	Lesser Jacana	*Microparra capensis*	R	LC
	Charadriidae	Black-headed Plover	*Vanellus tectus*	R	LC
		Three-banded Plover	*Charadrius tricollaris*	R	LC
	Scolopacidae	African Snipe	*Gallinago nigripennis*	R	LC
	Burhinidae	Spotted Thick-knee	*Burhinus capensis*	R	LC
		Senegal Thick-knee	*Burhinus senegalensis*	R	LC
	Glareolidae	Collared Pratincole	*Glareola pratincola*	PM	LC
		Common Ringed Plover	*Charadrius hiaticula*	PM	LC
		Egyptian Plover	*Pluvianus aegyptius*	ITM	LC
Passeriformes	Muscicapidae	Red-breasted Wheatear	*Oenanthe bottae*	R	LC
	Viduidae	Cuckoo Finch	*Anomalospiza imberbis*	R	LC
	Hirundinidae	Ethiopian Swallow	*Hirundo aethiopica*	R	LC
		Grey-rumped Swallow	*Pseudhirundo griseopyga*	ITM	LC
		African Plain Martin	*Riparia paludicola*	R	LC
Ciconiiformes	Ciconiidae	Yellow-billed Stork	*Mycteria ibis*	R	LC
		Abdim's Stork	*Ciconia abdimii*	R	LC
		Saddle-billed Stork	*E. senegalensis*	R	LC
		Marabou Stork	*Leptoptilos crumeniferus*	R	LC
Accipitriformes	Accipitridae	Lappet-faced Vulture	*Torgos tracheliotos*	R	EN
Gruiformes	Rallidae	Allen's Gallinule	*Porphyrio alleni*	AM	LC
		African Rail	*Rallus caerulescens*	R	LC
		Purple Swamphen	*Porphyrio porphyrio*	AM	LC
Falconiformes	Falconidae	Grey Kestrel	*Falco ardosiaceus*	R	LC
Caprimulgiformes	Apodidae	Little Swift	*Apus affinis*	R	LC
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	R	LC
Cultivated site:					
Passeriformes	Sturnidae	Red-winged Starling	*Onychognathus morio*	R	LC
	Viduidae	Pin-tailed Whydah	*Vidua macroura*	R	LC
	Motacillidae	African Pipit	*Anthus cinnamomeus*	R	LC

	Ploceidae	Little Weaver	*Ploceus luteolus*	R	LC
	Fringillidae	Yellow-fronted Canary	*Crithagra mozambica*	R	LC
		Yellow-rumped Seedeater	*Crithagra xanthopygia*	R	LC
Coraciiformes	Alcedinidae	Grey-headed Kingfisher	*Halcyon leucocephaha*	R	LC
Columbiformes	Columbidae	Namaqua Dove	*Oena capensis*	R	LC
Otidiformes	Otididae	Black-bellied bustard	*Lissotis melanogaster*	R	LC
Urban site:					
Passeriformes	Sturnidae	Lesser Blue-eared Starling	*Lamprotornis chloropterus*	R	LC
	Viduidae	Sahel Paradise Whydah	*Vidua orientalis*	R	LC
	Nectariniidae	Marico Sunbird	*Cinnyris mariquensis*	R	LC
		Scarlet-chested Sunbird	*Chalcomitra senegalensis*	R	LC
		Copper Sunbird	*Cinnyris cupreus*	R	LC
	Hirundinidae	Mosque Swallow	*Cecropis senegalensis*	R	LC
		Common House-Martin	*Delichon urbicum*	PM	LC
	Leiothrichidae	White-rumped Babbler	*Turdoides leucopygia*	R	LC
Columbiformes	Columbidae	Dusky Turtle-dove	*Streptopelia lugens*	R	LC
Musophagiformes	Musophagidae	White-cheeked Turaco	*Tauraco leucotis*	R	LC
Accipitriformes	Accipitridae	Long-crested Eagle	*Lophaetus occipitalis*	R	LC
Piciformes	Picidae	Cardinal Woodpecker	*Chloropicus fuscescens*	R	LC
		Nubian Woodpecker	*Campethera nubica*	R	LC
Caprimulgiformes	Apodidae	Nyanza Swift	*Apus niansae*	R	LC
Common birds recorded at more than one sites:					
Suliformes	Phalacrocoracidae	Great Cormorant [abcd]	*Phalacrocorax carbo*	R	LC
		Long-tailed Cormorant [abcd]	*Phalacrocorax africanus*	R	LC
	Anhingidae	African Darter [abd]	*Anhinga rufa*	R	LC
Accipitriformes	Accipitridae	African Fish Eagle [abcd]	*Haliaeetus vocifer*	R	LC
		Augur Buzzard [abc]	*Buteo augur*	R	LC
		Yellow-billed Kite [abc]	*Milvus aegyptius*	R	LC
		Black Kite [bc]	*Milvus migrans*	PM	LC

		Tawny Eagle [cd]	*Aquila rapax*	R	VU
		Greater Spotted Eagle [ad]	*Clanga clanga*	PM	VU
		Hooded Vulture [bd]	*Necrosyrtes monachus*	R	CR
		White-backed Vulture [ad]	*Gyps africanus*	R	CR
	Pandionidae	Osprey [ab]	*Pandion haliaetus*	R	LC
Bucerotiformes	Upupidae	African Hoopoe [abcd]	*Upupa Africana*	R	LC
	Bucerotidae	Hemprich's Hornbill [bc]	*Lophoceros hemprichii*	R	LC
		Silvery-cheeked Hornbill [ad]	*Bycanistes brevis*	R	LC
	Phoeniculidae	Black-billed Woodhoopoe [ad]	*Phoeniculus somaliensis*	R	LC
		Green Woodhoopoe [ad]	*Phoeniculus purpureus*	R	LC
Charadriiformes	Jacanidae	African Jacana [abcd]	*Actophilornis africanus*	R	LC
	Scolopacidae	Common Greenshank [abcd]	*Tringa nebularia*	PM	LC
		Common Snipe [bc]	*Gallinago gallinago*	PM	LC
		Common Sandpiper [abcd]	*Actitis hypoleucos*	PM	LC
		Green Sandpiper [bc]	*Tringa ochropus*	PM	LC
		Marsh Sandpiper [bc]	*Tringa stagnatilis*	PM	LC
		Little Stint [bc]	*Calidris minuta*	PM	LC
		Temminck's Stint [bc]	*Calidris temminckii*	PM	LC
		Ruff [abc]	*Philomachus pugnax*	PM	LC
	Recurvirostridae	Black-winged Stilt [bc]	*Himantopus himantopus*	PM	LC
	Laridae	Grey-headed Gull [bd]	*Larus cirrocephalus*	AM	LC
		Lesser Black-backed Gull [bd]	*Larus fuscus*	PM	LC
		Pallas's Gull [bd]	*Larus ichthyaetus*	PM	LC
		Slender-billed Gull [bd]	*Larus genei*	PM	LC
		White-winged Tern [abcd]	*Chlidonias leucopterus*	PM	LC
	Charadriidae	Kittlitz's Plover [abc]	*Charadrius pecuarius*	PM	LC
		Little Ringed-plover [abc]	*Charadrius dubius*	PM	LC
		Spur-winged Lapwing [abcd]	*Vanellus spinosus*	R	LC
Columbiformes	Columbidae	Mourning Dove [bcd]	*Zenaida macroura*	R	LC

		Bruce's Green-pigeon [abd]	*Treron waalia*	R	LC
		Laughing Dove [abcd]	*Streptopelia senegalensis*	R	LC
		Ring-necked Dove [acd]	*Streptopelia capicola*	R	LC
		Speckled Pigeon [abcd]	*Columba guinea*	R	LC
		Blue-spotted Wood-dove [ad]	*Turtur afer*	R	LC
Ciconiiformes	Ciconiidae	African Openbill [abc]	*Anastomus lamelligerus*	IAM	LC
		Woolly-necked Stork [ac]	*Ciconia episcopus*	ITM	NT
Passeriformes	Monarchidae	African Paradise Flycatcher [abcd]	*Terpsiphone viridis*	R	LC
	Nectariniidae	Beautiful Sunbird [abd]	*Cinnyris pulchellus*	R	LC
		Shining Sunbird [ad]	*Cinnyris habessinicus*	R	LC
		Tacazze Sunbird [ad]	*Nectarinia tacazze*	R	LC
		Variable Sunbird [ad]	*Cinnyris venustus*	R	LC
	Motacillidae	African Pied Wagtail [abc]	*Motacilla aguimp*	R	LC
		White Wagtail [bc]	*Motacilla alba*	PM	LC
		Yellow Wagtail [abcd]	*Motacilla flava*	PM	LC
		Plain-backed Pipit [ab]	*Anthus leucophrys*	R	LC
	Ploceidae	Black-headed Weaver [ac]	*Ploceus melanocephalus*	R	LC
		Lesser Masked Weaver [abd]	*Ploceus intermedius*	R	LC
		Spectacled Weaver [abcd]	*Ploceus ocularis*	R	LC
		Ruppell's Weaver [abcd]	*Ploceus galbula*	R	LC
		Northern Red Bishop [bc]	*Euplectes franciscanus*	R	LC
		Yellow Bishop [bc]	*Euplectes capensis*	R	LC
		Village Weaver [abcd]	*Ploceus cucullatus*	R	LC
		Vitelline Masked Weaver [acd]	*Ploceus vitellinus*	R	LC
		Yellow-mantled Widowbird [bc]	*Euplectes macroura*	R	LC
	Passeridae	Grey-headed Sparrow [abcd]	*Passer griseus*	R	LC
		Swainson's sparrow [abc]	*Passer swainsonii*	R	LC
	Sturnidae	Blue-eared Starling [abcd]	*Lamprotornis chalybaeus*	R	LC
	Hirundinidae	Red-rumped Swallow [abd]	*Cecropis daurica*	R	LC

		Lesser Striped Swallow [bd]	*Cecropis abyssinica*	R	LC
		Wire-tailed Swallow [ad]	*Hirundo smithii*	R	LC
		Collared Sand Martin [ac]	*Riparia riparia*	PM	LC
	Buphagidae	Red-billed Oxpecker [abd]	*Buphagus erythrorhynchus*	R	LC
	Acrocephalidae	Sedge Warbler [abc]	*A. schoenobaenus*	PM	LC
	Muscicapidae	Common Stonechat [ab]	*Saxicola torquatus*	PM	LC
		Northern Black Flycatcher [ad]	*Melaenornis edolioides*	R	LC
		Ruppell's Robin Chat [ad]	*Cossypha semirufa*	R	LC
	Turdidae	Groundscraper Thrush [bc]	*Psophocichla litsitsirupa*	R	LC
		African Thrush [abc]	*Turdus pelios*	R	LC
		Olive Thrush [ad]	*Turdus olivaceus*	R	LC
		Song Thrush [ab]	*Turdus philomelos*	R	LC
	Estrildidae	Bronze Mannikin [bc]	*Spermestes cucullata*	R	LC
		Cut-throat Finch [ad]	*Amadina fasciata*	R	LC
		Red-billed Firefinch [abcd]	*Lagonosticta senegala*	R	LC
		Red-cheeked Cordon Bleu [abcd]	*Uraeginthus bengalus*	R	LC
	Corvidae	Cape Crow [abc]	*Corvus capensis*	R	LC
		Pied Crow [bc]	*Corvus albus*	R	LC
	Pycnonotidae	Common Bulbul [abd]	*Pycnonotus barbatus*	R	LC
	Viduidae	Village Indigobird [bc]	*Vidua chalybeate*	R	LC
	Malaconotidae	Tropical Boubou [abd]	*Laniarius aethiopicus*	R	LC
	Locustellidae	Little Rush-warbler [ac]	*Bradypterus baboecala*	R	LC
	Alaudidae	Thekla Lark [bc]	*Calerida theklae*	R	LC
	Phylloscopidae	Willow Warbler [ab]	*Phylloscopus trochilus*	PM	LC
	Cisticolidae	Tawny-flanked Prinia [bc]	*Prinia subflava*	R	LC
	Laniidae	Common Fiscal [abcd]	*Lanius collaris*	R	LC
		Grey-backed Fiscal [bc]	*Lanius excubitoroides*	R	LC
Anseriformes	Anatidae	African Pygmy Goose [ad]	*Nettapus auritus*	R	LC
		Egyptian Goose [abcd]	*Alopochen aegyptiaca*	R	LC

		Spur-winged Goose [abcd]	*Plectropterus gambensis*	R	LC
		Fulvous Whistling-duck [abc]	*Dendrocygna bicolor*	R	LC
		White-faced Whistling-duck [abcd]	*Dendrocygna viduata*	R	LC
		Knob-billed Duck [abc]	*Sarkidiornis melanotos*	AM	LC
		Yellow-billed Duck [bc]	*Anas undulata*	PM	LC
		Maccoa Duck [bcd]	*Oxyura maccoa*	R	EN
		Northern Shoveler [bc]	*Anas Clypeata*	PM	LC
		Northern Pintail [bc]	*Anas acuta*	PM	LC
		Garganey [bc]	*Anas querquedula*	PM	LC
Coraciiformes	Alcedinidae	Pygmy Kingfisher [ac]	*Ceyx pictus*	R	LC
		Giant Kingfisher [abd]	*Megaceryle maxima*	R	LC
		Malachite Kingfisher [ad]	*Alcedo cristata*	R	LC
		Pied Kingfisher [abcd]	*Ceryle rudis*	R	LC
		Striped Kingfisher [ac]	*Halcyon chelicuti*	R	LC
		Woodland Kingfisher [ac]	*Halcyon senegalensis*	R	LC
	Meropidae	European Bee-eater [ad]	*Merops apiaster*	PM	LC
		Green Bee-eater [abc]	*Merops orientalis*	R	LC
		Little Bee-eater [abcd]	*Merops pusillus*	R	LC
Pelecaniformes	Threskiornithidae	African Spoonbill [abc]	*Platalea alba*	R	LC
		Glossy Ibis [abc]	*Plegadis falcinellus*	AM	LC
		Hadada Ibis [abcd]	*Bostrychia hagedash*	R	LC
		Sacred Ibis [abcd]	*Threskiornis aethiopicus*	R	LC
		Wattled Ibis [abc]	*Bostrychia carunculata*	R	LC
	Ardeidae	Cattle Egret [abcd]	*Bubulcus ibis*	R	LC
		Great Egret [abc]	*Ardea alba*	R	LC
		Purple Heron [abc]	*Ardea purpurea*	R	LC
		Grey Heron [abcd]	*Ardea cinerea*	PM	LC
		Squacco Heron [abcd]	*Ardeola ralloides*	R	LC
		Intermediate Egret [abcd]	*Mesophoyx intermedia*	R	LC

		Little Egret [abcd]	*Egretta garzetta*	R	LC
	Scopidae	Hamerkop [abcd]	*Scopus umbretta*	R	LC
	Pelecanidae	Great White Pelican [abcd]	*Pelecanus onocrotalus*	R	LC
Gruiformes	Rallidae	Blake Crake [abd]	*Amaurornis flavirostra*	R	LC
		Common Moorhen [abd]	*Gallinula chloropus*	R	LC
		Lesser Moorhen [abd]	*Paragallinula angulate*	R	LC
		Red-knobbed Coot [abc]	*Fulica cristata*	R	LC
	Gruidae	Black-crowned Crane [abcd]	*Balearica pavonina*	R	VU
Piciformes	Lybiidae	Black-billed Barbet [abd]	*Lybius guifsobalito*	R	LC
		Double-toothed Barbet [abd]	*Lybius bidentatus*	R	LC
	Picidae	Grey Woodpecker [ad]	*Dendropicos goertae*	R	LC
Psittaciformes	Psittacidae	Black-winged Lovebird [abd]	*Agapornis taranta*	R	LC
Cuculiformes	Cuculidae	Blue-headed Coucal [abd]	*Centropus monachus*	R	LC
Musophagiformes	Musophagidae	Eastern Plantain-eater [abcd]	*Crinifer zonurus*	R	LC
Caprimulgiformes	Apodidae	Horus Swift [bd]	*Apus horus*	R	LC
Coliiformes	Coliidae	Speckled Mousebird [abcd]	*Colius striatus*	R	LC

Notes: R – Resident; PM – Palearctic Migrant; ITM – Intra-tropical Migrant; IAM – Intra-African Migrant; AM – Afrotropical Migrant; CR – Critically endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern.

Highest bird species richness and abundance was observed at the grazing site, while the urban site had the lowest richness and abundance. The Island site had the highest Shannon-Wiener diversity (H' = 4.21) while the urban site had the highest Shannon-Wiener evenness (E = 0.57) (Table 3.4).

Table 3.4 Diversity indices estimates of bird species in different sampling sites.

Site	**Island**	**Grazing**	**Cultivar**	**Urban**
No. of species	125##	140	101**	98** ($F_{(3, 80)} = 11.70$, $p < 0.0001$)
Abundance	1414***	3045	1413***	1078*** ($F_{(3, 80)} = 52.67$, $p < 0.0001$)
H’	4.21	3.93	3.86	4.02
E	0.54	0.36	0.47	0.57
D	0.97	0.97	0.96	0.97

* indicates significant differences ($p < 0.01$; $p < 0.001$) between grazing and other sites

# indicates significant difference ($p < 0.01$) between island and urban sites

3.3.1 Encounter rate

Of the 209 bird species encountered, 46 were abundant, 85 were common, 69 were frequent, and 9 were uncommon (Fig. 3.3). The most abundant species were *Dendrocygna viduata* (White-faced whistling duck), (8.14%), *Fulica cristata* (Red-knobbed coot), (7.98%), and *Alopochen aegyptiaca* (Egyptian goose), (6.66%).

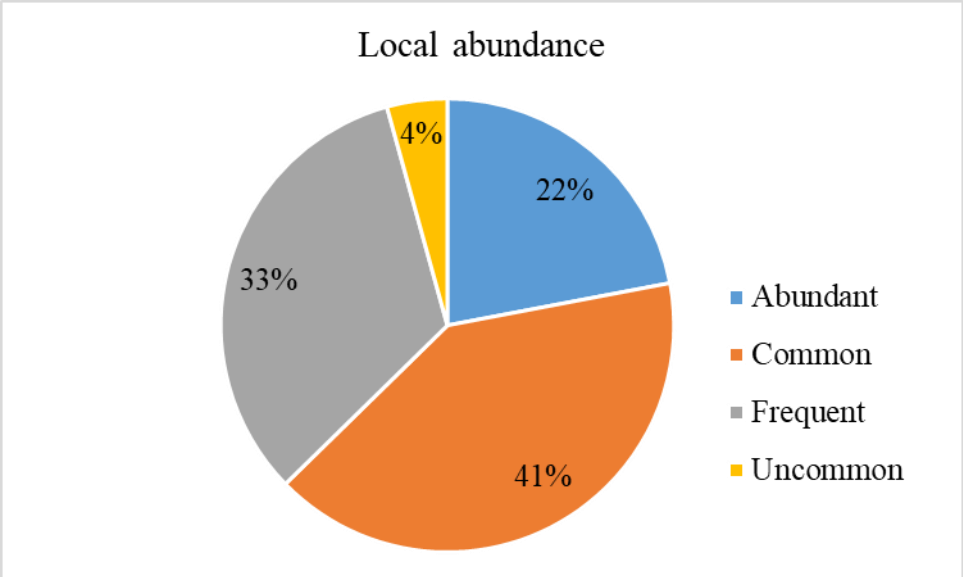

Figure 3.3 Percentage of relative abundance categories of bird species in the study area.

Across sampling sites, frequent species were dominant followed by common species while abundant species had the lowest encounter rate at all sites (Table 3.5 and Fig. 3.4).

Table 3.5 Encounter rates of bird species at selected sampling sites at lake Tana.

	Island	Grazing	Cultivar	Urban
Abundant	5	13	5	2
Common	23	30	24	20
Frequent	80	74	50	60
Uncommon	17	22	21	16

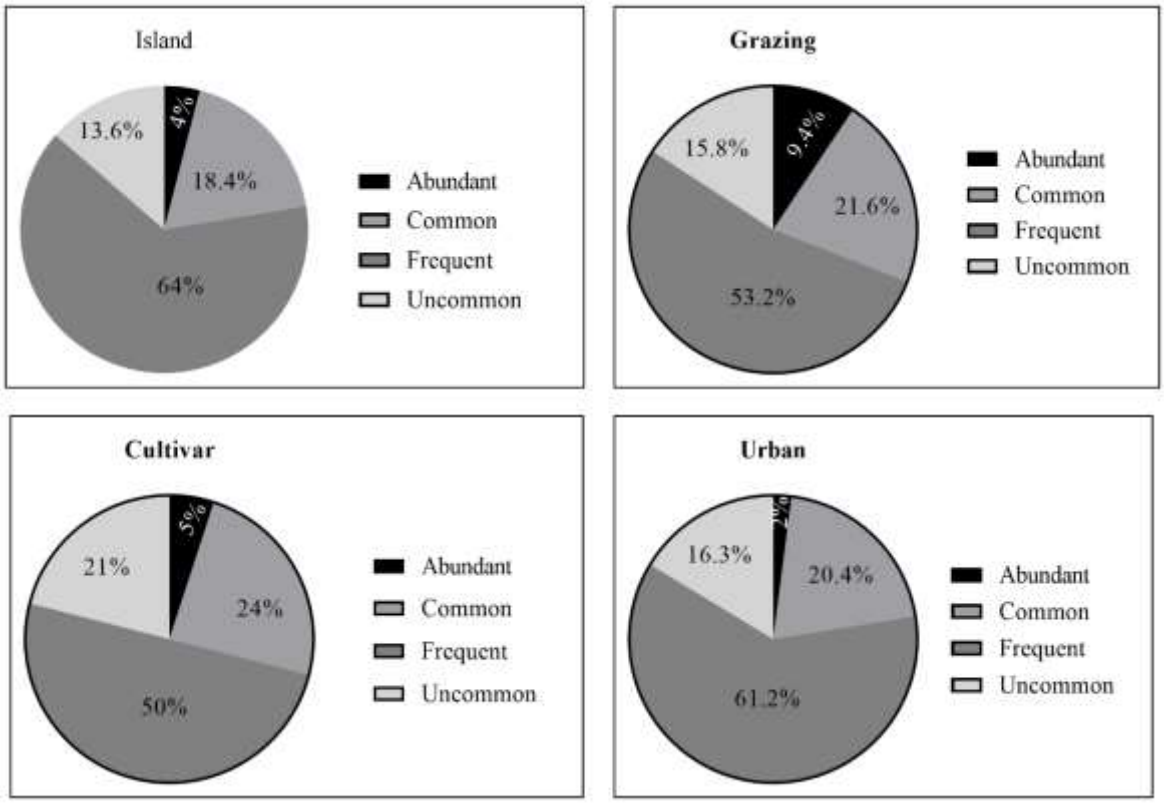

Figure 3.4 Site-specific relative abundance of bird species based on encounter rate categories

3.3.2 Relative Diversity

The Anatidae family had the highest RDi value, indicating represented families, at the grazing site (Table 3.6). Anatidae and Ardeidae families had high number of species at the Island site. The Anatidae and Ploceidae families were high at the cultivar site, while the Columbidae and Nectariniidae families were high at the urban site.

Table 3.6 The relative diversity (RDi) of various avian families at selected sites of lake Tana.

Family	RDI			
	Island	Grazing	Cultivar	Urban
Accipitridae	2.39	2.39	1.91	2.87
Acrocephalidae	0.96	0.48	0.48	_
Alaudidae	_	0.48	0.48	_
Alcedinidae	2.87	0.96	2.39	1.44
Anatidae	4.31	5.26	4.78	2.39
Anhingidae	0.48	0.48	_	0.48
Apodidae	_	0.96	_	0.96
Ardeidae	4.31	4.31	3.35	2.39
Bucerotidae	0.48	0.48	0.48	0.48
Buphagidae	0.48	0.48	_	0.48
Burhinidae	_	0.96	_	_
Charadriidae	1.91	2.39	1.44	0.48
Ciconiidae	0.96	2.39	0.96	_
Cisticolidae	_	0.48	0.48	_
Coliidae	0.48	0.48	0.48	0.48
Columbidae	2.87	1.91	2.39	3.35
Corvidae	0.48	0.96	0.96	_
Cuculidae	0.48	0.48	0.00	0.48
Estrildidae	1.44	1.44	1.44	1.44
Falconidae	_	0.48	_	_
Fringillidae	_	_	0.96	_
Glareolidae	_	1.44	_	_
Gruidae	0.48	0.48	0.48	0.48
Hirundinidae	1.44	2.39	0.48	2.39
Jacanidae	0.48	0.96	0.48	0.48
Laniidae	0.96	0.96	0.96	0.48
Laridae	0.96	2.39	0.48	2.39
Leiothrichidae	_	_	_	0.48
Locustellidae	0.48	_	0.48	_
Lybiidae	1.44	0.96	_	0.96
Malaconotidae	0.48	0.48	_	0.48
Meropidae	1.44	0.96	0.96	0.96
Monarchidae	0.48	0.48	0.48	0.48
Motacillidae	1.44	1.91	1.91	0.48
Muscicapidae	1.91	0.96	_	0.96
Musophagidae	0.48	0.48	0.48	0.96
Nectariniidae	2.39	0.48	_	3.35

Oriolidae	0.48	_	_	_
Otididae	_	_	0.48	_
Pandionidae	0.96	0.96	0.48	_
Passeridae	0.96	0.96	0.96	0.48
Pelecanidae	0.48	0.96	0.48	0.48
Phalacrocoracidae	0.96	0.96	0.96	0.96
Phoeniculidae	0.96	_	_	0.96
Phylloscopidae	0.48	0.48	_	_
Picidae	0.48	_	_	1.44
Ploceidae	3.35	3.35	4.31	2.39
Podicipedidae	0.00	0.48	_	_
Psittacidae	0.48	0.48	_	0.48
Pycnonotidae	0.48	0.48	0.48	_
Rallidae	2.39	3.35	0.48	1.44
Recurvirostridae	_	0.48	0.48	_
Scolopacidae	1.44	4.31	3.83	0.96
Scopidae	0.48	0.48	0.48	0.48
Strigidae	0.48	_	_	_
Sturnidae	0.48	0.48	0.96	0.96
Threskiornithidae	2.39	2.39	2.39	0.96
Turdidae	1.44	1.44	0.96	0.48
Upupidae	0.48	0.48	0.48	0.48
Viduidae	_	0.96	0.96	0.48

3.3.3 Similarity

There was a 52% similarity in avian species between grazing and cultivar sites and 27% avian species similarity between cultivar and urban sites. Similarity decreases as one moves from grazing vs. cultivar, island vs. urban, island vs. grazing, island vs. cultivar, grazing vs. urban, and cultivar vs. urban (Table 3.7).

Table 3.7 Jaccard's similarity index of bird species in the selected sites during the study period.

Sites	Common species	Similarity index
Island vs. grazing	80	0.43
Island vs. cultivar	67	0.42
Island vs. urban	74	0.50
Grazing vs. cultivar	82	0.52
Grazing vs. urban	60	0.35
Cultivar vs. urban	41	0.27

3.4 Discussion

The lowest diversity observed at cultivar is due to increased agriculture (Stave et al., 2017). Diversity and abundance were lower in urban and cultivar, indicating that lake Tana biosphere reserve is in poor health. Similarly, Israel and Timar (2018), and Babu (2015) reported that degradation of wetlands resulted in the extinction of some and reduction of other species. *Gyps africanus* (White-backed Vulture), *Necrosyrtes monachus* (Hooded Vulture), *Trigonoceps occipitalis* (White-headed Vulture), *Aquila rapax* (Tawny Eagle), *Clanga clanga* (Greater Spotted Eagle), *Balearica pavonina* (Black-crowned Crane), *Oxyura maccoa* (Maccoa Duck), *Cyanochen cyanoptera* (Blue-winged Goose), *Aythya nyroca* (Ferruginous Duck) constitute flagship species. *Balearica pavonina* (Black-crowned Crane), *Plectropterus gambensis* (Spur-winged Goose), *Alopochen aegyptiaca* (Egyptian Goose) use farmland for foraging and are in conflict with humans during crop harvest. Grazing site with high species richness and low species evenness is due to presence highly abundant species –*Fulica cristata* (Red-knobbed Coot), *Alopochen aegyptiaca* (Egyptian Goose), and *Dendrocygna viduata* (White-faced Whistling Duck).

4.0 Seasonal distribution of birds (both resident and migrant)

4.1 Introduction

The Lake Tana basin is home to both resident and migratory bird species. Several migratory birds visit the lake because of its geographical location along the East Africa West Asia flyway migration route (Somveille et al., 2013; Ash and Atkins, 2009). Thousands of birds migrate through the lake basin; many stay for the non-breeding season, while others migrate to Africa (Ash and Atkins, 2009). According to Aynalem (2017) the lake Tana area is a home to both Afrotropical and Palaearctic migrant bird species. However, detailed study is required to assess the distribution and status of resident and migratory birds for conservation purposes.

4.2 Materials and methods

4.2.1 Bird survey - as described under 3.2.3

4.2.2 Resident vs. migrant - Determination of local status was done based on keys (Aynalem, 2013; Ash and Atkins, 2009) and migrants classified as: Palaearctic, Intra-tropical, Afro-tropical, Intra-African. The status of bird species as resident, Palearctic migrant and intra-

African migrant were categorized using field guide (Aynalem, 2013; Ash and Atkins, 2009). Migratory birds' status categorized as follows:

1. Intra-African migrant: a species that breeds in one part of Africa and spends the rest of the year in another. Such a bird may only appear seasonally to or from breeding and non-breeding areas. It may be sometimes used for shorter-distance African migrants.
2. Palearctic migrant: a species that breeds in the Palearctic (during the northern summer) and spends the non-breeding season (the northern winter) in Sub-Saharan Africa; such birds may only be passage migrants in our region, but if they stay for the winter, they are often referred to as winter visitors.
3. Intra-tropical migrant: species that migrate within the tropics.
4. Afrotropical: a species that migrant within Sub-Saharan African.

4.2.3 Data analysis – Data of the months was pooled over the two year sampling period (June 2019 – May 2021). June to August constituted Summer, September to November constituted Autumn, December to February constituted Winter and March to May constituted Spring (Fazzini et al., 2015; Mcsweeney et al., 2010). Shannon-Wiener diversity, Shannon-Wiener evenness, Simpson's index of dominance indices and encounter rate were calculated to measure the spatial and temporal variation in species diversity and abundance (Hammer et al., 2001).

4.3 Results

During the study period, residents such as *Ciconia abdimii*, *Asio capensis*, *Streptopelia decipiens*, *Anthus cinnamomeus*, *Riparia paludicola*, *Rallus caerulescens*, *Zapornia pusilla*, *Ardea melanocephala*, *Vanellus tectus*, *Spermestes cucullata*, *Delichon urbicum*, *Cinnyris cupreus*, *Anomalospiza imberbis*, *Hirundo aethiopica*, *Ardea goliath*, *Ploceus luteolus*, *Cecropis senegalensis*, *Vidua macroura*, *Onychognathus morio*, *Ephippiorhynchus senegalensis*, *Chalcomitra senegalensis*, *Crithagra xanthopygia*, and *Turdoides leucopygia* were observed only in winter season. On the other hand, *Falco ardosiaceus*, *Lamprotornis chloropterus*, and *Campethera nubica* were only seen in the summer. In autumn, *Torgos tracheliotos*, *Lophaetus occipitalis*, *Vidua orientalis*, and *Leptoptilos crumenifer* were observed. In spring season, *Anas sparsa*, *Ploceus baglafecht*, *Cyanochen cyanoptera*, *Butorides striata*, *Tachybaptus ruficollis*, *Apus niansae*, *Aquila rapax*, and *Thalassornis leuconotus* were encountered.

Overall, the highest species richness was recorded during winter season at all the four sites. The spring season had the highest abundance at the Island, grazing, and urban sites, while the winter season had the highest abundance at the cultivar. The diversity was highest in the winter season at island and grazing sites, while it was highest in autumn at cultivar and urban sites. The evenness of species was highest in autumn at island and urban sites, and in summer at grazing and cultivar sites (Table 4.1).

Table 4.1 Seasonal diversity, evenness, and dominance indices of avifauna across sampling sites

Site	Season	No. species	Abundance	H'	E	D
Island	Summer	66	627	3.80	0.68	0.97
	Autumn	74	645	3.95	0.70	0.97
	Winter	94	1054	4.05	0.61	0.98
	Spring	93	1089	3.85	0.50	0.95
Grazing	Summer	72	1777	3.35	0.39	0.93
	Autumn	82	1514	3.38	0.36	0.93
	Winter	97	2670	3.46	0.33	0.94
	Spring	88	2835	3.22	0.29	0.92
Cultivar	Summer	52	510	3.50	0.64	0.96
	Autumn	59	700	3.49	0.56	0.95
	Winter	72	1379	3.26	0.36	0.93
	Spring	62	1140	3.22	0.40	0.93
Urban	Summer	54	433	3.53	0.63	0.95
	Autumn	67	557	3.78	0.65	0.97
	Winter	74	1015	3.66	0.52	0.95
	Spring	72	1102	3.38	0.41	0.91

Table 4.2 Encounter rates of bird species across sampling sites and seasons

Site	Season	Abundant	Common	Frequent	Uncommon
Island	Summer	2	12	45	10
	Autumn	-	12	53	9
	Winter	4	23	51	16
	Spring	2	16	61	14
Grazing	Summer	7	22	33	10
	Autumn	5	19	42	16
	Winter	14	21	45	17
	Spring	11	18	47	12
Cultivar	Summer	1	12	33	10

	Autumn	2	13	30	14
	Winter	6	15	35	16
	Spring	5	15	33	9
Urban	Summer	1	7	36	11
	Autumn	1	10	43	13
	Winter	4	18	43	9
	Spring	3	17	42	10

Among the bird species identified, 47 are migrants, of which 37 species were Palearctic migrants, 05 were Afrotropical migrants, 04 were Intra-tropical migrants, and 01 intra-African migrant (Fig. 4.1). Long-distance migrants made up 87.2% of all identified migrant birds. Thirty eight migrant species were encountered in the 1st year (June 2019-May 2020), while 39 species were identified in the 2nd year (June 2020-May 2021) of sampling. Thus, 30 migrant species returned to the study area the following year. In contrast, 08 species did not return to the sampling sites, and 10 new species visited the study area in the second year. During the first year of the study period, 81.1% of the migrant species were observed during winter, followed by spring (75.7%) and autumn (37.8%). During 2020-2021, 87.2% were observed in winter, 48.7% in autumn and 51.3% observed in spring. Grazing site had the highest migrant species (80.9%, 38 species).

Table 4.3 Species richness and abundance of Resident (R) and, Migrant (M) avian species

Site	**Season**	**No. of species**		**Abundance**		**%**	
		R	M	R	M	R	M
Island	Summer	66	-	627	-	100	-
	Autumn	68	6	611	34	91.9	8.1
	Winter	79	15	913	141	84	16
	Spring	79	14	983	106	84.9	15.1
Grazing	Summer	65	6	1611	166	90.3	9.7
	Autumn	65	17	1265	249	79.3	20.7
	Winter	66	31	2181	489	68	32
	Spring	60	28	2172	663	68.2	31.8
Cultivar	Summer	52	-	510	-	100	-
	Autumn	49	10	617	83	83.1	16.9
	Winter	55	17	1132	247	76.4	23.6
	Spring	45	17	944	196	72.6	27.4

Urban	Summer	54	-	433	-	100	-
	Autumn	62	5	524	33	92.5	7.5
	Winter	67	7	950	65	90.5	9.5
	Spring	67	5	1061	41	93.1	6.9

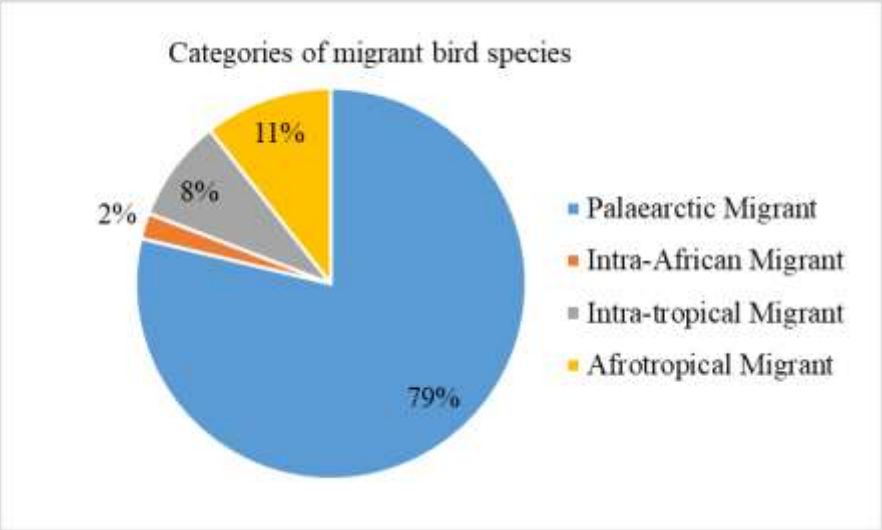

Figure 4.1 Categories of migrant species richness in the study area as per Aynalem (2013) and Ash and Atkins (2009).

Table 4.4 Classification of migrant species recorded at sampling sites during the four seasons.

Site	Season	Palaearctic	Intra-African	Intra-tropical	Afrotropical
Island	Autumn	4	-	-	1
	Winter	12	1	1	1
	Spring	11	1	-	1
Grazing	Summer	5	-	-	-
	Autumn	10	1	2	3
	Winter	25	-	3	3
	Spring	21	1	1	5
Cultivar	Autumn	9	-	1	-
	Winter	15	-	-	2
	Spring	15	1	-	1
Urban	Autumn	5	-	-	-
	Winter	7	-	-	-
	Spring	5	-	-	-

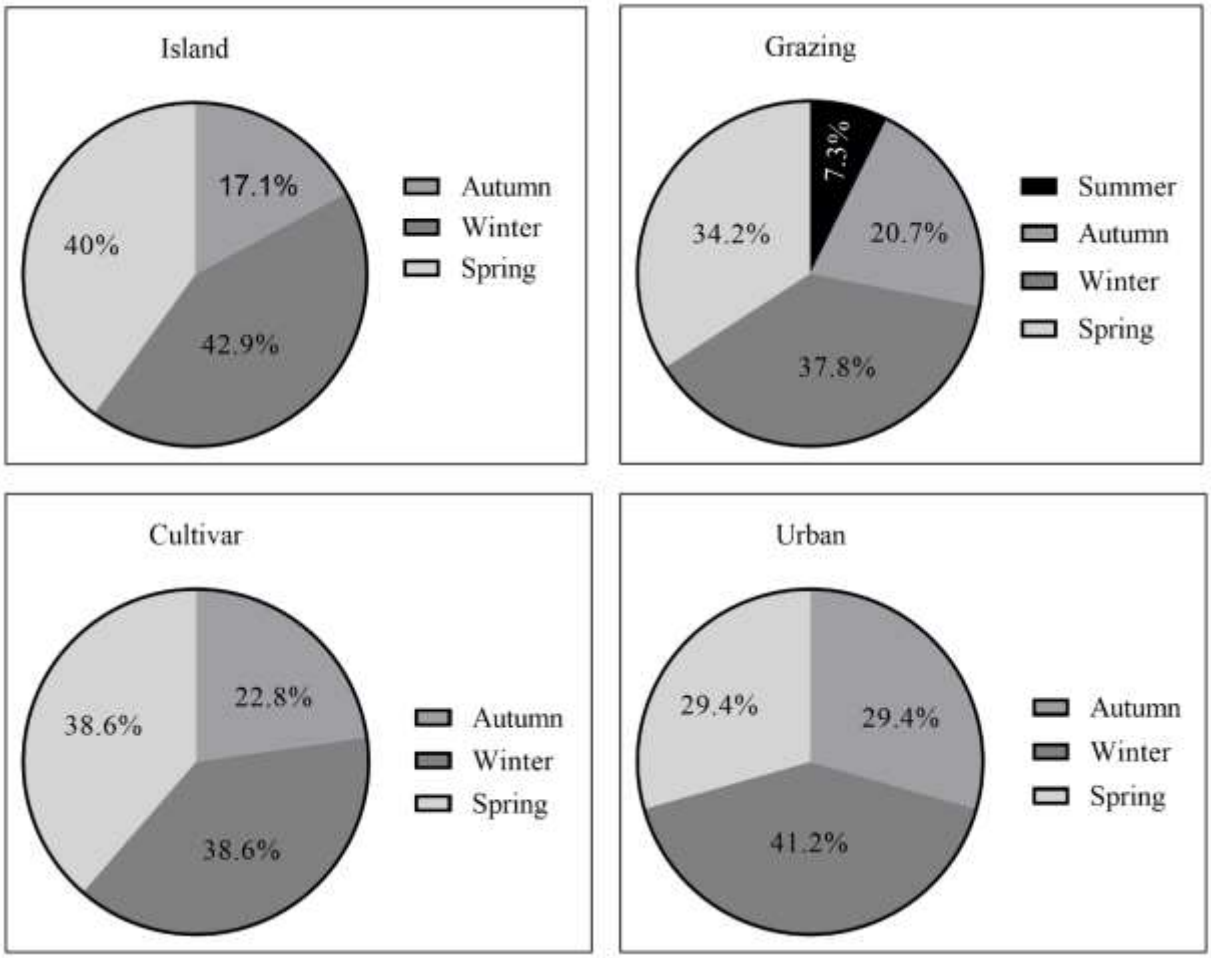

Figure 4.2 Season-wise distribution of migrant species in percentage across sampling sites

4.4 Discussion

The highest species diversity observed in winter is due to overwintering migrants due to and adequate food resources (Sharma et al., 2018; Russell et al., 2014). Most Palaearctic migratory birds overwinter in lake Tana due to geographical location along Black Sea/Mediterranean, and West Asia-East Africa flyways (Ash and Atkins, 2009; Boere and Stroud, 2006). Species richness decreased in summer due to return of migratory populations and/or resident species engaged in breeding activities (Maneas et al., 2020). Few migrant bird species were observed already in autumn. Most migrant species were observed in winter followed by spring throughout the study period.

5.0 Avifauna-plant relationships in terms of habitat and food

5.1 Introduction

The Lake Tana Area's vegetation includes Dry Evergreen Afromontane forest, Combretum-Terminalia woodland, Grasslands, marshes, and swamps (Friis et al., 2010). Food availability and exploitation patterns in a specific habitat determine bird distribution and community structure (Pang et al., 2017; Palmer et al., 2003). Food abundance varies seasonally (Gregory et al., 2003) and influences seasonal bird migration (Maeda, 2001). Seasonal effects (Kumar and Sahu, 2020; Nsor et al., 2018) and human disturbance are two factors that influence foraging behavior (Asefa et al., 2017). Some birds are foraging in a crop field that either damage crops or feeds on pests (Sausse and Lévy, 2021; Puckett et al., 2009). But, little is known about the feeding ecology and bird assemblage structure in Lake Tana. Hence, this study documented the flora of Lake Tana and determined diet composition and feeding patterns of birds.

5.2 Materials and methods

5.2.1 Flora

All plant species found within a 50-meter radius of the point are recorded as per Bibby et al. (2000). In each sampling site, plants used for nesting, roosting, and feeding were recorded (Buckland et al., 2007; Keith, 2000). Species identification was performed using field guides (Negash, 2021; Friis et al., 2010; Llamas, 2003) and confirmed with samples kept in the National Herbarium, Addis Ababa University, Ethiopia, for further confirmation.

5.2.2 Diets

Diets were collected and identified using the droppings analysis technique (Michalski et al., 2011). Feeding and roosting sites of birds were selected to collect droppings (Sutherland, 2006; Bellis and Profke, 2003). The samples were collected in a separate bottle and preserved in 70% alcohol. To identify birds' diets, dropping samples were examined under a dissecting microscope (Moreby and Stoate, 2000; Pokhrel and Budha, 2015). Identification was made by using reference collection (Hurlbert et al., 2021; Pokhrel and Budha, 2015; Cappers and Bekker, 2013; Michalski et al., 2011).

5.2.3 Feeding guilds

The feeding guilds of the birds were classified into carnivores, omnivores, granivores, frugivores and herbivores as per Lopes et al. (2016) and González-Salazar et al. (2014).

5.2.4 Data analysis

Plant-bird associations were summarized in tabular form by organizing the most visited plants by bird species for feeding, roosting, and nesting. Feeding observations and dropping collections for each bird species were consolidated family wise and then integrated into the respective guilds. The percentage of identified food items are presented in a pie chart. Two-way ANOVA was used to determine whether bird diets varied significantly across seasons and sites, with Tukey's post-test for multiple comparisons set at significant level of $p < 0.05$.

5.3 Results

A total of 114 plant species from 57 families and 34 orders were identified. The family Fabaceae was dominant with 9 species. The most frequently visited plant species by birds were *Ficus sycomorus, Cordia africana, Ficus vasta, Mimusops kummel, Ficus sur, Eragrostis tef,* and *Zea mays* (Table 5.1).

Table 5.1 Plant species frequented by avifauna for feeding, roosting, and nesting.

Plant species	**Bird species**	**Plant species**	**Bird species**
Cordia africana	*Bycanistes brevis*	*Ficus vasta*	*Bycanistes brevis*
	Crinifer zonurus		*Treron waalia*
	Treron waalia		*Pogonornis bidentatus*
	Pogonornis bidentatus		*Crinifer zonurus*
	Bycanistes brevis		*Lamprotornis chalybaeus*
	Lybius undatus		*Crinifer zonurus*
	Cinnyris habessinicus		*Tauraco leucotis*
Ficus sycomorus	*Colius striatus*	*Syzygium guineense*	*Lamprotornis chalybaeus*
	Crinifer zonurus		*Crinifer zonurus*
	Bycanistes brevis		*Treron waalia*
	Treron waalia		*Pogonornis bidentatus*
	Pogonornis bidentatus		*Bycanistes brevis*
	Lybius undatus		*Lybius undatus*
	Tauraco leucotis		*Ploceus cucullatus*
Cyperus papyrus	*Ploceus cucullatus*	*Typha latifolia*	*Zapornia flavirostra*
	Ploceus vitellinus		*Anhinga rufa*

	Centropus monachus	*Ardea cinerea*
	Ploceus taeniopterus	*Ardeola ralloides*
	Pycnonotus barbatus	*Balearica pavonina*
	Passer swainsonii	*Bubulcus ibis*
	Passer griseus	*Ardea alba*

The faecal droppings were collected from 75 bird species belonging to 39 families and 15 orders. There were 40 carnivores, 16 omnivores, 10 granivores, 6 frugivores, and 3 herbivores among the 75 bird species. Carnivores dominated the grazing (63.3%) and island (55%) sites, while granivores (36.4%) dominated the cultivar site. There were no recorded frugivores in the grazing and cultivar sites, and no herbivores were observed in the urban site.

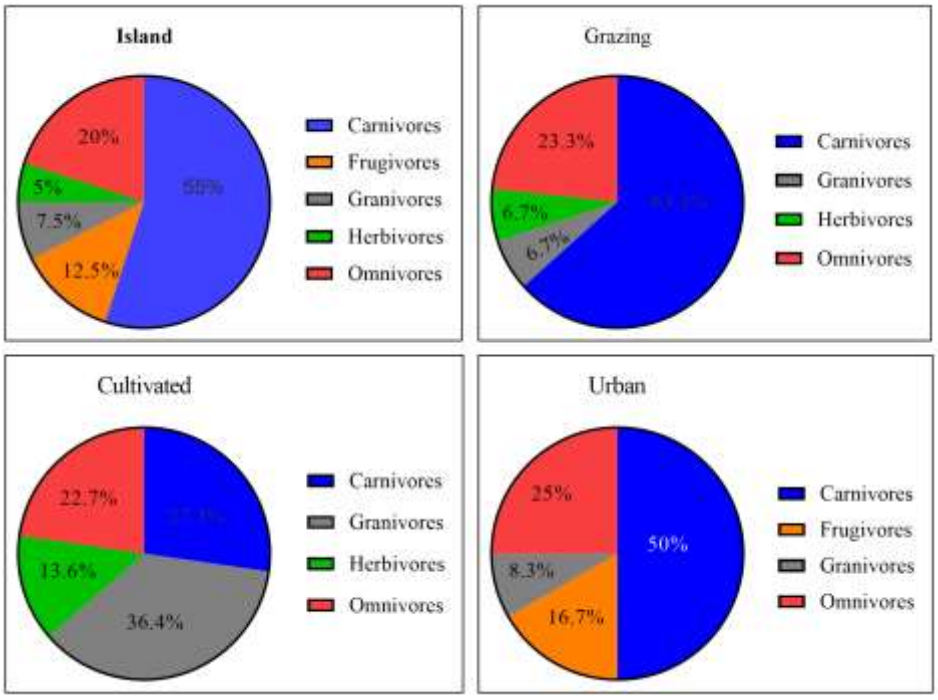

Fig. 5.1 Distribution of various feeding guilds in percentage across sampling sites.

From collected droppings, 1209 fragments were identified and recorded. Of these, 457 were plant parts, 416 were insect parts, 177 were fish parts, 47 spider parts, and 41 snail parts, and 71 were unidentified.

Fig. 5.2 Bird droppings used for diet identification: (A-C) – Beetle parts, (D) – Bee labium, (E&F) – Cockroach parts, (G) – Cricket parts, (H&I) – Ant parts, (J&K) – Fly parts, (L&M) – Fish scales & otoliths (N) – *Phidippus audax*, (O&P) – Weevil leg parts, (Q) – Harvestman fang parts, and (R-T) – Grasshopper parts. Scale bar = 1mm.

Table 5.2 Season-wise quantification of diet fragments across sampling sites

Site	Season	No. of diet fragments of animal and plant parts					
		Insect	Plant	Fish	Snail	Spider	Unidentified
Island	Summer	46	25	8	9	8	4
	Autumn	41	51	9	2	4	13
	Winter	32	35	7	5	1	10
	Spring	28	36	13	1	1	13
Grazing	Summer	34	24	23	2	4	8
	Autumn	38	29	16	4	2	-
	Winter	27	26	13	-	-	2
	Spring	22	29	20	3	3	4
Cultivar	Summer	16	30	7	2	1	-
	Autumn	24	30	7	4	6	-
	Winter	21	20	5	2	-	1
	Spring	18	26	3	2	5	2
Urban	Summer	26	25	6	-	1	1
	Autumn	24	41	14	3	4	6
	Winter	11	17	10	2	3	4
	Spring	14	13	14	4	4	2

When we take overall food preferences into consideration, significant differences in food items were observed between seasons ($F_{(3,120)} = 6.46$, $p < 0.001$); between food categories ($F_{(5,120)} = 118.9$, $p < 0.0001$) with significant interaction ($F_{(15,120)} = 3.64$, $p < 0.0001$; two-way ANOVA). Post hoc tests revealed that insect and plant diets were significantly higher when compared to other food items in summer, winter, and spring ($p < 0.001$). Insect diets were significantly higher in summer ($p < 0.05$), while plant diets were significantly higher ($p < 0.0001$) in autumn as compared to animal parts.

5.3 Discussion

Granivorous birds relied on agricultural habitats, whereas carnivorous and omnivorous birds foraged in grazing and urban areas. The island site remains an important habitat for forest bird species, while common species can be found in cultivated and urban areas. Numerous bird species used a variety of food resources depending on habitat and season. The result revealed that birds are drawn to cultivated and island areas to feed on seasonal resource peaks. The granivore birds dominated cultivated site could be due to fields left fallow after harvest

(Moorcroft et al., 2002; Siriwardena et al., 2000). Agricultural habitats are useful for foraging and cover resources for many bird species (Johnson et al., 2011). The grazing site was dominated by carnivores and omnivores can be explained by availability of insects, seeds, and vegetable matter (Neilly and Schwarzkopf, 2019). The difference in food items across seasons could be attributed to the abundance of insects (Jahn et al., 2010), fruits (Darosci et al., 2021; Bender et al., 2017), and seeds (Greer et al., 2007). The highest abundance of insect diets in summer might correspond to insect life strategies (Leonhardt et al., 2016). While the highest plant diets in autumn could be due to the availability of abundant fruits, seeds, and grains (González-Varo et al., 2022; Mosissa, 2019).

6.0 Recording and analysis of bird vocalizations

6.1 Introduction

An acoustic bird survey has been used as an alternative to point counts to improve monitoring efforts (Klingbeil and Willig, 2015). It is a non-invasive and low-cost method of assessing biodiversity (Sueur et al., 2008). Bird songs and calls are distinct and identifiable at the individual level, either by ear or through a spectrogram analysis (Sutherland et al., 2004). Although bird vocalizations are important for population dynamics, monitoring, communication, and determining the occurrence of bird species in many countries (Farina and Gage, 2017), no study has ever been conducted and published in Ethiopia. Hence, this research aimed to record and analyzed bird vocalizations for species identification, survey and conservation at lake Tana biosphere reserve, Ethiopia.

6.2 Materials and methods

6.2.1 Sound recordings

Bird sound recordings conducted with an Olympus LS-12 recorder and microphone (Sennheiser ME 66 shotgun). The target species for recordings were chosen based on active vocalizations observed during the field survey. GPS was used to place regular 200 m apart point stations across the study area to define sample locations as per Lellouch et al. (2014) and Pieretti et al. (2011). Bird species were identified from recordings using spectrogram aural and visual examination (Marck et al., 2022; O'Reilly et al., 2018; Livezey, 2017). All sounds were analyzed on a PC using Raven Pro V1.6 software

6.2.2 Data analysis

Spectrogram measurements such as bandwidth (Hz), maximum/minimum frequency (Hz), peak frequency, duration (s), and amplitude (dB) were taken using the following parameters: DFT size is 512, the frequency resolution is 86.1 Hz, and window type is Hann. Acoustic parameters such as call length/duration, maximum/minimum frequency (Hz), amplitude (dB), peak frequency were calculated from the spectrograms. For site-specific analysis, spectrograms of species observed across sampling sites were used. Correlation was used to test the relationship between acoustic parameters across sites.

6.3 Results

The vocalizations of 45 avian species, belonging to 30 families, and 14 orders were recorded and were analyzed using spectrogram.

High frequency (16220.88 ± 417.95 kHz) calls were recorded from *Vanellus spinosus* (Spur-winged lapwing), while low frequency (29.90±36.32 Hz) calls were recorded from *Columba guinea* (Speckled pigeon).

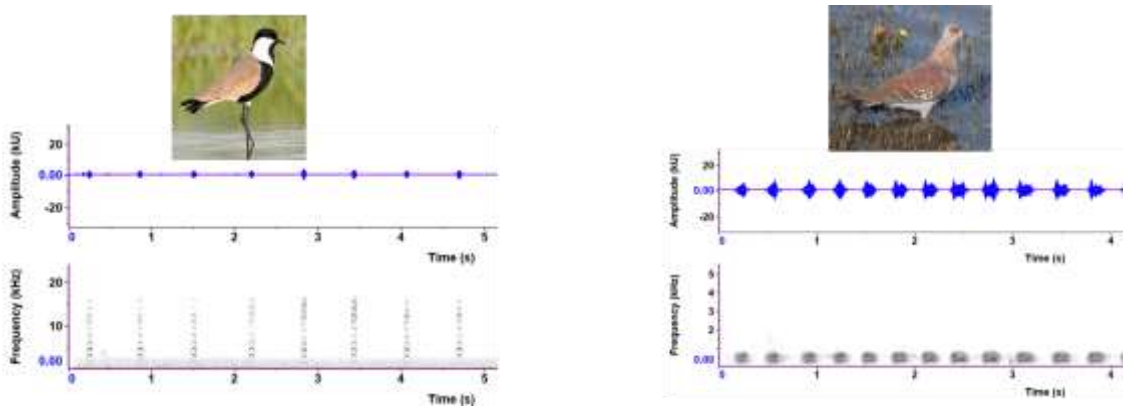

Figure 6.1 Spectrogram showing high frequency calls from *Vanellus spinosus* (left), and the low frequency from *Columba guinea* (right).

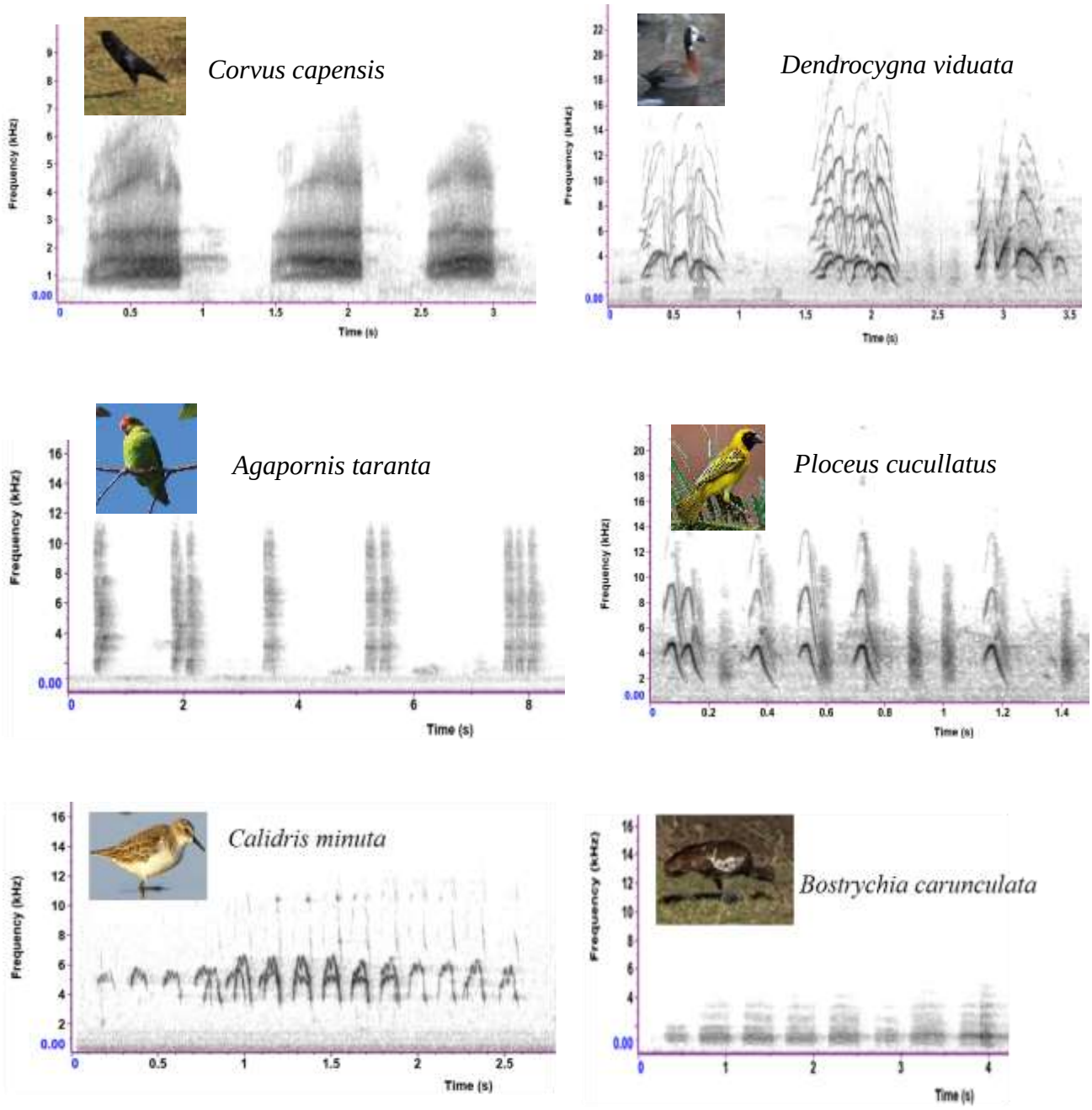

Figure 6.2 Spectrograms of selected species demonstrating variation in length, frequency, modulation.

Only calls of *Alopochen aegyptiaca*, and *Lamprotornis chalybaeus* were recorded across all sampling sites and analysed for acoustic parameters. *Alopochen aegyptiaca* had the highest bandwidth (10959.55 ± 1019.24 Hz), peak frequency (1526.25 ± 63.58 Hz), and peak amplitude (4855.80 ± 755.67 dB) at urban site, whereas duration was high (0.23 ± 0.03) at the grazing site.

Lamprotornis chalybaeus had highest bandwidth (11434.88 ± 2919.66 Hz), and peak amplitude (9027.70 ± 6758.78 dB) at cultivar. Peak frequency was high (2576.09 ± 631.98 Hz) at urban sites. Call length or duration was higher (0.55 ± 0.26) at grazing site.

Alopochen aegyptiaca's calls' bandwidth and peak amplitude were positively correlated at Island ($r = 0.72$, $p = 0.018$), and Cultivar ($r = 0.55$, $p = 0.004$). Peak amplitude and duration were positively correlated in Cultivar ($r = 0.60$, $p = 0.001$), and negatively correlated at Urban site ($r = -0.41$, $p = 0.044$).

Lamprotornis chalybaeus's calls' bandwidth and peak frequency ($r = 0.52$, $p = 0.011$), bandwidth and peak amplitude ($r = 0.46$, $p = 0.027$), peak frequency and peak amplitude ($r = 0.62$, $p = 0.002$) were positively correlated at Island site. Peak frequency and peak amplitude ($r = 0.69$, $p = 0.0002$), duration and peak frequency ($r = 0.58$, $p = 0.004$) and peak amplitude ($r = 0.77$, $p = 0.00002$) were positively correlated at the Grazing site. Bandwidth and peak amplitude ($r = 0.56$, $p = 0.005$) and peak frequency ($r = 0.49$, $p = 0.018$) were positively correlated at Cultivar. Peak frequency and peak amplitude ($r = -0.62$, $p = 0.001$) were negatively correlated at Urban site.

6.4 Discussion

The highest bandwidth, peak frequency and peak amplitude in the urban and cultivar sites could be attributed to the impact of habitat on bird vocalizations. Due to habitat disturbances, birds have been shown to sing louder, higher, and longer (Halfwerk et al., 2018). The record of the lowest minimum frequency from *Columba guinea* is similar to that reported by Zeyl et al. (2020) and is advantageous for long-distance signaling (Hart et al., 2020). This is the first report of calls of endemic species *Agapornis taranta* and *Bostrychia carunculata* in Lake Tana. It is also the first report of variation in call parameters based on anthropogenic disturbances in Ethiopia.

7.0 Assessing anthropogenic impact on birds and their habitats in the selected sites

7.1 Introduction

In Ethiopia, LULC has undergone rapid change, becoming one of the country's major environmental issues. Currently, LULC change is the primary cause of biodiversity loss, with extensive habitat conversion resulting in a decline in biodiversity and ecological function (Croxall et al., 2012; Lemoine et al., 2007). However, cultivation, habitat destruction, wetland

deforestation, invasive weeds, illegal fishing, pollution, and sedimentation pose threats to the lake (Goshu and Aynalem, 2017; Gashaw and Fentahun, 2014). Furthermore, there is still a lack of spatially explicit LULC change data, and no in-depth study has been conducted to date to generate empirical data that would aid in policy decisions to save the threatened environment and dependent avifauna. Change detection is useful for LULC related applications, including agriculture, urbanization, and habitat management (Serra et al., 2008). Understanding habitat changes, patterns, and human disturbances are critical for effective avifauna management (Tewabe and Fentahun, 2020). Therefore, the research presented here selected LULC change as one of the major indicators of longitudinal anthropogenic impact with the goal of better understanding LULC change and its impact on avifauna resources in lake Tana.

7.2 Materials and methods

7.2.1 Bird survey - as described in 3.2.3

7.2.2 LULC change analysis

The entire lake Tana biosphere reserve was classified into LULC classes by remote sensing and GIS techniques. Following a pilot study in June 2019, the sampling sites were systematically selected within each LULC class. Sites from each category were chosen to test the hypothesis about the effects of LULC changes on avifauna resources. Landsat images of the area for 1987, 1997, 2007, and 2017 were obtained from the website of the USGS. Extensive data analysis using GIS and remote sensing techniques was carried out over the last 30 years. ERDAS IMAGINE 2015 and ArcGIS10.8 were used for LULC change analysis. To detect land-use change dynamics over time, five land-use types were considered for image classification: forest, agricultural land, grassland, built-up land, and water bodies.

7.2.3 Data analysis - The LULC change was detected using supervised image classification using ERDAS Imagine software and the online Google Earth Pro application. The cumulative LULC change depicted in percentage was obtained by observing the difference from 1987 to 2017. The Shannon-Wiener diversity index was chosen because it is more reflective in nature and can predict environmental health (Supriatna, 2018). Differences in avifaunal biodiversity indices vis-a-viz the LULC sites were observed using one-way ANOVA followed by the Tukey post-hoc comparison test.

7.3 Results

7.3.1 Land use land cover dynamics

During all the periods of assessment, on average, the largest portion of the lake Tana biosphere reserve is covered by agricultural land (47.71 ± 2.29%) followed by water bodies (43.98 ± 0.2%), besides grasslands (5.73 ± 1.74%), forest cover (2.38 ± 0.8%) and built-up land (0.17 ± 0.15%). Over the three decades, forest cover decreased by 53.21% compared to 1987. Over three decades, agricultural land use increased by about 11.65%, while grasslands decreased by about 49.84%. During the same period, water bodies decreased by 1.13%. The LULC change detection revealed an increase in agricultural land by 5.32% and built-up land by 0.33% between 1987 and 2017. In the same period, the lake water size was reduced by 0.50%, whereas grasslands decreased by 3.26%, and forest cover decreased by 1.90%.

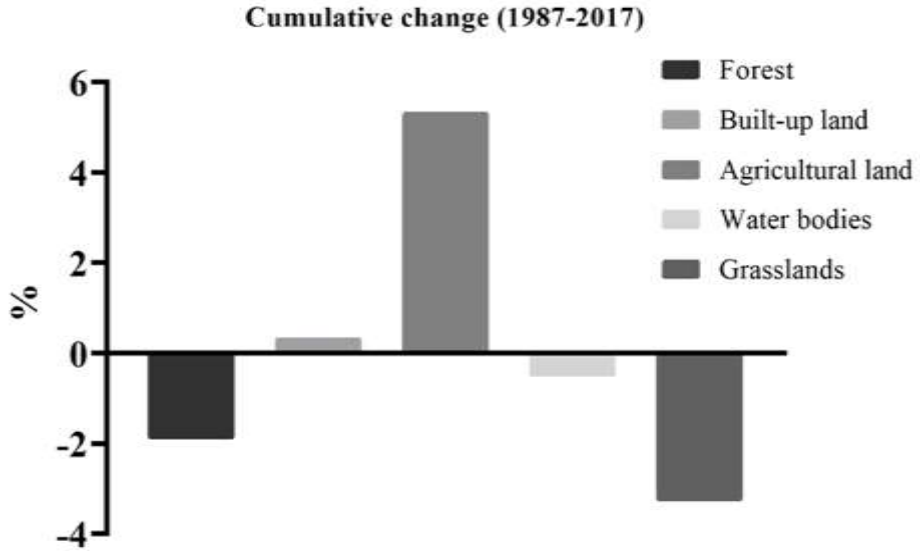

Figure 7.1. The cumulative LULC change (1987-2017) graph was obtained by subtracting the LULC class area of 1987 from the LULC class area of 2017 for each respective class, and by converting each LULC class area into a percentage.

7.3.2 Avifauna and LULC change

In total, 188 bird species belonging to 59 families and 20 orders were identified. Of these, 27.1% were migrants and resident migrants. There were 93.09% species of least concern (LC), 1.60% critically endangered (CR), 2.13% endangered (EN), 1.60% vulnerable (VU), and 1.60% near threatened (NT). The grasslands had the highest bird species richness and abundance, while built-up land had the lowest abundance (Table 7.1).

Table 7.1. Diversity indices of bird species in different LULC classes: agricultural land, grasslands, built-up land, forests, and water bodies.

Sites	No. of species	Abundance	H'	E	D
Agricultural land	79	1276	3.77	**0.55**	0.97
Grasslands	**107**	**2767**	3.63	0.35	0.95
Built-up land	84	932	3.74	0.50	0.95
Forests	105	1856	**3.80**	0.43	0.96
Water bodies	65	1255	3.08	0.33	0.91

Grasslands had the highest bird species richness and abundance, while built-up land had the lowest abundance. The forest site had the highest Shannon-Wiener diversity (H' = 3.80) and the agricultural land had the highest Shannon-Wiener evenness (E = 0.55). Analysis of variance of the bird species richness ($F_{(4, 55)} = 6.612$, $p = 0.0002$) and abundance ($F_{(4, 55)} = 7.025$, $p = 0.0001$) showed significant difference among the LULC types. Species richness was significantly increased in grasslands when compared to agriculture ($p < 0.05$) and waterbodies ($p < 0.05$). Species richness was significantly increased in forests when compared to agricultural land ($p < 0.05$), water bodies ($p < 0.01$) and built-up land ($p < 0.05$). Species abundance was significantly increased in grasslands when compared to agriculture ($p < 0.01$), built-up land ($p < 0.001$) water bodies ($p < 0.01$) and forests ($p < 0.05$), (Table 7.1).

7.4 Discussion

The cumulative result revealed that the lake is highly threatened by cultivation, urbanization, settlement, and overgrazing, and the water bodies were reduced in the past four decades. In the Lake Tana biosphere reserve, more than 5.3% of bird species are considered to be threatened with global extinction. The decreasing trend of water bodies, forests, and grasslands could be attributed to intensive irrigation in lake Tana area (Abera, 2017; Asres, 2016; Tewabe, 2015). According to Nyssen and Adgo (2019), the lake is under severe stress as a result of farming, overgrazing, water extraction, and irrigation. Low bird species richness and abundance were observed in agricultural and built-up land sites. Sewnet (2015), and Gashaw and Fentahun (2014) have reported on the declining trend of important species due to increased LULC change with spatiotemporal distribution being influenced by LULC dynamics (Scholtz et al., 2017; Royan et al., 2014).

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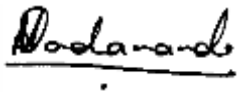

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PhD Guide